ment, which, afterward, was found to have an excellent vacuum and to read apparently as at first; this method of removing air is rarely successful. No. 1019, the errors of which apparently have remained unchanged since it was purchased, appears to be the best of the four barometers and is considered the standard of the observatory.

Director Patterson states that the Newman standard, imported in 1839 and compared with the standard of the Royal Society at Somerset House, originally had a correction of −0.004 inch. Whether the British standard has been changed from that of the Royal Society is not known, but, in any case, the correction, now +0.003 inch, has not changed more than 0.007 inch in 93 years.

The author acknowledges indebtedness to Mr. Arthur Rotch, of Boston, who kindly contributed the expenses of travel incidental to this work, and to the Instrument Division of the Weather Bureau, and to Director Patterson of the Canadian Meteorological Office, for providing necessary facilities and assistance.

At the time the comparisons described herein were completed (early in 1933) no normal or absolute standard was in use in America. Since then two important advances in precision barometry have occurred, of which one is the new primary standard of the National Physical Laboratory, England, and the other the construction of an instrument at the United States Bureau of Standards. News of the latter will be welcomed by American meteorologists who have hoped for the maintenance of an absolute standard of pressure in this country. The new British standard is described in a paper, A New Primary Standard Barometer, by J. E. Sears and J. S. Clark, in the Proceedings of the Royal Society, A, vol. 139, 1933 of which the following summary is quoted:

> The paper contains an account of a new primary standard barometer recently installed at the National Physical Laboratory to serve as a basis of reference for all measurements relating to barometric pressures.
>
> The body of the instrument is constructed in stainless steel, with optically flat parallel glass windows through which the mercury surfaces are observed. These windows can be removed, if necessary, for cleaning, and the vacuum can be restored by means of suitable pumps whenever the instrument is required for use. The average temperature of the mercury column is ascertained by means of a mercurial thermometer with a bulb 30 inches long, immersed in a hole bored in the stainless-steel body parallel to the barometric column.
>
> Two micrometer microscopes are fixed, one above the other, to a massive vertical column which can be translated laterally so as to view either the mercury surfaces, or the divisions of a standard invar scale set up at the side of the barometer body. The height of each mercury surface is taken to be the mean of two microscope readings, one of the direct image of a horizontal cross wire projected into the space above the mercury, and one of the reflection of this image in the mercury.
>
> The design and general accuracy of workmanship are such that individual readings should be correct to the order of 0.001 mm. In practice it is found that the mean residual error of a single observation is of the order of 0.005 mm., this being probably attributable in the main to minute fluctuations of barometric pressure which are continually taking place, even when atmospheric conditions are reasonably steady.

The new instruments of the Bureau of Standards are described briefly in the following extract from a letter recently received from the Director of the Bureau:

> In testing mercurial barometers we are using a Fuess barometer as the standard which had been modified so as to have an all-glass cistern. Special methods of filling the tube have been developed in which the mercury is distilled into the tube while under a high vacuum. We have found that the vacuum above the mercury column when so filled holds for a number of years. This has been checked by intercomparison between 4 Fuess barometers, 3 of which are of the modified type. This intercomparison has usually taken place immediately after the refilling of one of the instruments.
>
> In order to eliminate possible errors due to the loss of vacuum above the mercury column we have recently constructed a mercurial barometer in which the vacuum space above the mercury column is connected to a mercury vapor pump and to a McLeod gage. It is thus possible to both control and measure the degree of vacuum. The scale and vernier from one of the Fuess barometers is used on this instrument which by comparison with the standard meter bar can be relied on to about 0.01 mm. We estimate the over-all accuracy which will be secured with this new arrangement to be ± 0.05 mm. of mercury. This accuracy is better than that of any portable barometer which is likely to be submitted for test.

METEOROLOGICAL CONDITIONS PRECEDING THUNDERSTORMS ON THE NATIONAL FORESTS

1. WESTERN AND CENTRAL OREGON

By W. R. STEVENS

[Weather Bureau, Washington, D. C., November 1934]

The great menace of thunderstorms to forested areas in all the western fire-weather districts of the Weather Bureau has been emphasized many times by all officials connected with the fire-weather work and by forest-protection agencies. In the region under consideration in this paper (western and central Oregon), lightning causes more than one-half of all the forest fires.

It is not apparent to the student of the daily weather map that lightning should be such a great fire-causing factor in this region, because few thunderstorms are observed at first-order Weather Bureau stations in this area. However, at higher elevations in the national forests of western and central Oregon, thunderstorms are frequent, and occasionally so widespread, with so many cloud to ground flashes, that forest-protection agencies are not able to cope with the situation unless they are warned at least a few hours in advance.

It is the purpose of this paper to discuss thunderstorms, particularly in relation to the national forests of western and central Oregon, and to present an analysis of the meteorological conditions that ordinarily precede their occurrence in that region.

CAUSES OF THUNDERSTORMS

The thunderstorm is the result of vigorous vertical convection of humid air. The thunder and lightning which attend the storm play no part in its mechanism.

When vertical convection of air occurs, the air is said to be unstable. Instability may be brought about by strong surface heating; by overrunning of one layer of air by another at a considerably lower temperature; by underrunning and uplift of a saturated layer of air by a denser layer; and by forced ascent of humid air masses up mountain slopes.

There are two classes of thunderstorms, (1) the heat thunderstorm, and (2) the cyclonic thunderstorm. This classification is based upon the cause of the instability which produces the storms. There are other classifications of thunderstorms, but this one suits best for the present discussion.

Conditions are favorable for the genesis of heat thunderstorms when the pressure is nearly uniform and slightly below normal over a wide area. When this situation prevails, the winds are light and the surface air becomes strongly heated, resulting in vigorous vertical convection currents and cumulo-nimbus clouds, provided the decrease of temperature with altitude (lapse rate) exceeds the dry adiabatic rate of 1° C. per 100 meters, and sufficient water vapor is present to produce raindrops in the rising air. Genesis of heat thunderstorms is favored by drafts up the sides of mountain ranges, mountain peaks, and valleys. Storms of this type are very likely to form after 2 or 3 days of unusually warm weather, when the lower air has become so heated that convection extends to high altitudes.

Cyclonic thunderstorms may occur in the southeast quadrant of a cyclone, in which case the high lapse rate necessary for rapid convection results from the different directions of the lower and upper air currents. The surface air in the southeast quadrant flows from warmer regions, while the currents aloft, which flow more nearly from the west, are often sufficiently colder to induce the convection necessary to the production of thunderstorms.

Cyclonic thunderstorms also occur along the "cold front" of a cyclone. Warm tropical winds are associated with the eastern portion of a cyclone, while cold polar winds prevail over the western portion. The boundary between these two systems of winds is usually well marked, and is known as a "cold front." The cold air advances in the form of a wedge. Friction at the surface of the earth retards the advance of the cold air, while the cold air aloft advances unimpeded. This results in a wedge with its point some distance above the ground. Beneath the overhanging front of cold air, warm air is entrapped, which results in strong convection, either through the overrunning cold air or out in front of it, and the squally winds that are always associated with the passage of a cold front.

That thunderstorms do not occur at times when the pressure distribution appears favorable for their inception is due to certain factors that are not apparent from surface observations. For instance, the lapse rate may not be high enough to permit strong convection currents, or there may not be sufficient water vapor present to cause condensation within the limits of the vertical currents that do form.

In this study, moisture conditions at the surface, as indicated by the vapor pressure, are used in the discussion of thunderstorm forecasting. It is true that temperature and moisture conditions aloft are as important, or more so, as those at the surface in producing thunderstorms, but observations of these are not available for the region under consideration.

PRECIPITATION IN THUNDERSTORMS

Rain does not fall continuously during a thunderstorm, (in fact, none may fall), but generally in very heavy showers. Everyone is familiar with the fact that rain after almost ceasing may begin again with great violence after a lightning flash.

Condensation occurs in the ascending current as soon as the temperature of the rising air is reduced to the dewpoint. The raindrops do not fall immediately, but are carried upward. Small raindrops fall very slowly through still air, and can be carried upward by a relatively slow ascending current. Lenard [1] has shown that raindrops cannot fall through air of normal density whose upward velocity is greater than 8 meters per second, nor fall themselves with greater velocity through still air. When raindrops form larger than 5 or 6 millimeters in diameter, they are unstable, and immediately break up into smaller drops.

The ascending current in a thunderstorm is not steady, so that the raindrops intermittently rise and fall, alternately breaking up into smaller drops and coalescing into larger ones. The drops which get to the edge of the ascending current, or reach the top of the current and spread out horizontally, fall to the ground, and produce the heavy rain during the early part of the storm.

The occasional occurrence of hail in thunderstorms is definite proof that ascending currents frequently are very violent and extend to high altitudes. The raindrops are carried upward into the region of freezing temperature, where they congeal and obtain a coating of snow. After a time, during a lull in the ascending current, they fall to the region of liquid drops where they gather a layer of water, part of which is frozen by the low temperature of the kernels. Thus, a hailstone which makes a number of journeys from the rain level to the snow level alternately receives a covering of ice and snow. The sizes of the hailstones are roughly proportional to the strength of the ascending currents. However, since the weights of the stones vary approximately as the cubes of their diameters, while the supporting force of the current varies approximately as the square of the diameters of the hailstones, a limiting size is quickly reached.

Humphreys [2] states that experiment shows that the vertical velocity necessary to sustain a hailstone 1 inch in diameter is at least 59 miles per hour, and 116 miles per hour if the stone is 3 inches in diameter.

Formation of raindrops is essential to the occurrence of lightning. However, it is a common occurrence in semiarid regions, and less frequently in other sections, to see lightning but no rain reaching the ground. The reason for this phenomenon is that the lower air is so dry that the drops are evaporated before they reach the earth's surface.

INSTABILITY IN NATIONAL FORESTS OF WESTERN AND CENTRAL OREGON

The convective processes which produce the majority of thunderstorms in the national forests of western and central Oregon are induced by strong surface heating in connection with a trough of low pressure which extends in a general north-south direction from British Columbia to northwestern Mexico. The convection is aided by drafts up the mountain slopes, and probably at times by overrunning of relatively cool air currents.

Occurrence of the cyclonic type of thunderstorm in this region is very rare.

DATA

The thunderstorm observations used in this study (1925–31, inclusive) were very kindly furnished by Dr. Thornton T. Munger, Director of the Pacific Northwest Forest Experiment Station at Portland, Oreg. These data have been made the subject of an article by William G. Morris of that station entitled "Lightning Storms and Fires on the National Forests of Oregon and Washington." A summary of Mr. Morris' paper immediately follows this article on page 370.

TYPES OF THUNDERSTORM DAYS

Three types of thunderstorm days have been defined by Mr. Morris. The "local" storm day is one on which one or a few storms occur that affect only a small area

[1] Lenard, P., Met. Zeit., 21; 249, 1904.

[2] Humphreys, W. J., Physics of the Air, second edition, p. 346.

of the region. The "general" type either has many small storms which affect two-thirds of the area, or has one or more storms which make a continuous track at least two-thirds the length of the region. The "intermediate" storm day is one on which the storms are more widespread than on the "local" day, but less extensive than on the "general" day.

In this paper, the terms "intermediate" and "general" are replaced by "scattered" and "wide-spread", respectively, because they correspond better with forecast terminology.

A "local" storm day causes only one forest fire, on the average. Fires started on this type of day are, as a rule, quickly controlled and suppressed without any extra preparations being made. For this reason, when it is obvious from the weather map or relationships given in this paper that if any thunderstorms occur at all they will be sufficient to produce only a "local" storm day, a forecast of thunderstorms should include a modifying term, such as "local", to indicate to forestry officials that meteorological conditions are not menacing, but that a few storms are likely to develop. Modifying terms such as "scattered" and "wide-spread" would indicate that storms of a more dangerous type, and to a degree defined by the respective terms, are likely to develop.

SEASON OF LIGHTNING FIRE HAZARD

The season of lightning fire hazard begins in western and central Oregon in June and ends in September, as a rule.

The following table shows the number of thunderstorm days on the national forests of this area from June to September, inclusive, classified with respect to type, for the 7 years studied.

	Local	Scattered	Wide-spread	Total
June	32	5	1	38
July	43	16	13	72
August	43	13	10	66
September	32	13	5	50

The season included in this study is the months of July and August, as the above figures indicate that the thunderstorm situation is most acute during this period.

RELATIONSHIPS

A number of relationships between various meteorological elements and the occurrence of thunderstorms will be presented in this paper and in succeeding articles treating of other national forests. It is emphasized that these relationships are intended as adjuncts to the daily weather maps. It is not presumed that better forecasts can be made from these relationships alone than those that an experienced forecaster can make who is familiar with meteorological conditions that ordinarily produce thunderstorms in the region. However, it is believed that they are valuable aids in thunderstorm forecasting, because they indicate when conditions are relatively safe, that is, if thunderstorms develop at all the probability is great that there will be only a sufficient number to produce a "local" storm day; and when conditions are likely to be dangerous.

It must be borne in mind that only a 7-year period is included in this study, and therefore the conclusions reached necessarily are provisional.

Use of barometric pressure reduced to sea level as one of the factors is obvious, as it has been known for a long time that there is a relation between pressure distribution and thunderstorm activity.

Pressure differences between various stations are used as an indication of the north-south trough of low pressure mentioned above, or the presence of a cyclonic disturbance to the north of the region.

Vapor pressure also is used to indicate whether moisture conditions are favorable for thunderstorm inception.

METEOROLOGICAL CONDITIONS IN MORNING AND THUNDERSTORM ACTIVITY SAME DAY

When the thunderstorm reports were plotted against the 8 a. m. E. S. T. pressure at Seattle, a rather definite line of demarcation at 30.05 inches was revealed. When the pressure was above this figure, those thunderstorms that occurred the same afternoon and evening were usually only sufficient to produce a "local" storm day. During the seven July months studied, only three "wide-spread" and four "scattered" storm days occurred when the morning pressure at Seattle was above 30.05 inches, as was the case on 53 percent of the days. Four "wide-spread" and two "scattered" storm days occurred during the August months under this condition, which prevailed on 50 percent of the days. On the other hand, when the pressure was below 30.05 inches, the storms were more frequent and more dangerous.

On all "scattered" and "wide-spread" storm days that occurred with pressure above 30.05 inches at Seattle, the morning pressure at Roseburg was below 30.10 inches during July, and below 30.12 inches in August.

No "wide-spread" storm days occurred during July when the Seattle pressure was below 30.05 inches and the Roseburg pressure higher than 29.98 inches. Three "scattered" storm days occurred under these circumstances out of a total of 44 days. Here again we find a very sharp line of demarcation. Whenever the pressure in the morning is below 30.05 inches at Seattle in July and lower than 30 inches at Roseburg, the day must be regarded as potentially dangerous, especially if other meteorological conditions indicate that thunderstorms are probable (fig. 1).

When the Seattle pressure is below 30.05 inches and the Roseburg pressure higher than 30.02 inches in August, the day is relatively safe (fig. 2). Not a single "scattered" or "wide-spread" storm day occurred under these conditions out of a total of 23 days.

Another important factor in thunderstorm activity which is apparent in August, but shows up to only a small extent in July is the 24-hour pressure change at Portland. Any day in August that the pressure is below 30.05 inches at Seattle, below 30.04 inches at Roseburg, and the pressure at Portland has fallen 0.04 inch or more in 24 hours must be regarded as dangerous (fig. 3).

During the July months, it was found that when the pressure is below 30.05 inches at Seattle, the vapor pressure above 0.35 inch at Roseburg, and in addition the pressure at Roseburg is not more than 0.08 inch higher than at Baker, a dangerous situation exists. Under these circumstances many thunderstorm days of the "scattered" and "wide-spread" types occur. However, any day that the Seattle pressure is below 30.05 inches and does not meet the other requirements is relatively safe (fig. 4). Out of a total of 50 such cases, there was only 1 "wide-spread" and 1 "scattered" storm day. When the pressure is above 30.05 inches at Seattle, the vapor pressure at Roseburg and the pressure difference between Roseburg and Baker seem to have little significance. During August, however, all the "wide-spread" and "scattered" storm

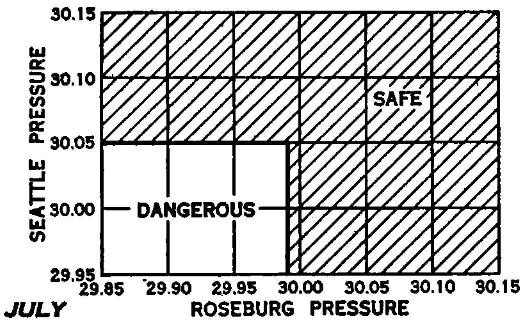

Fig. 1.

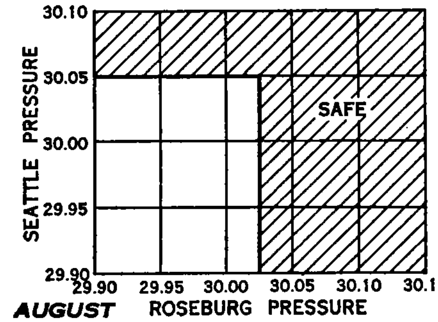

Fig. 2.

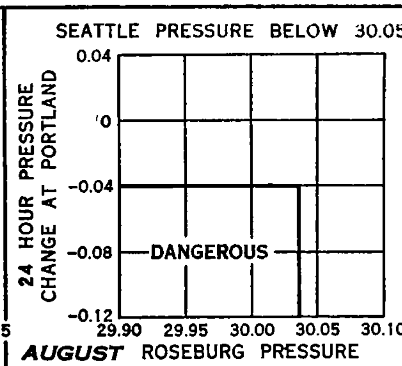

Fig. 3.

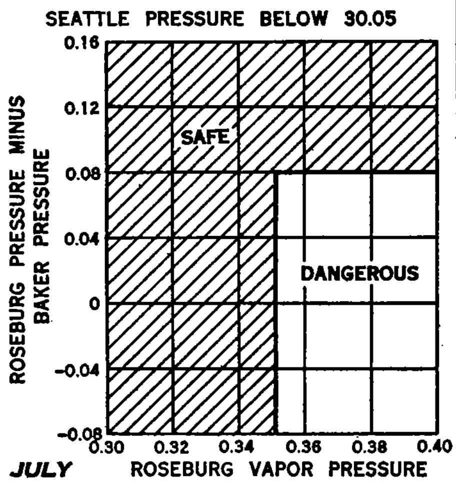

Fig. 4.

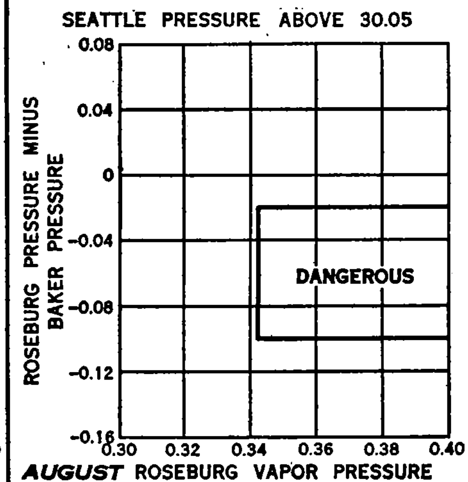

Fig. 5.

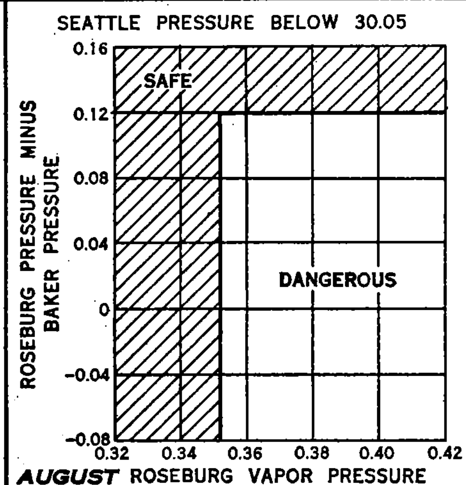

Fig. 6.

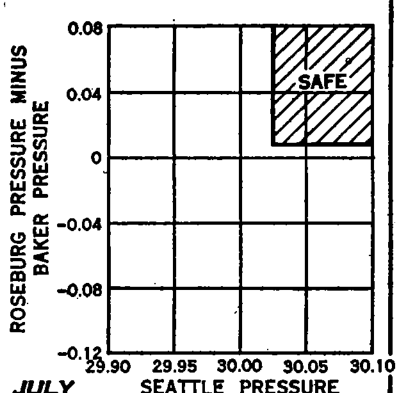

Fig. 7.

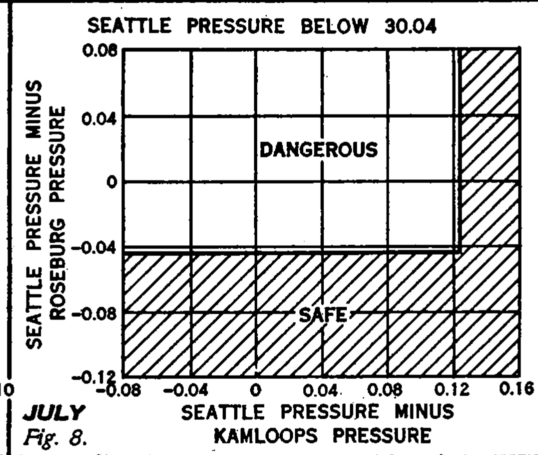

Fig. 8.

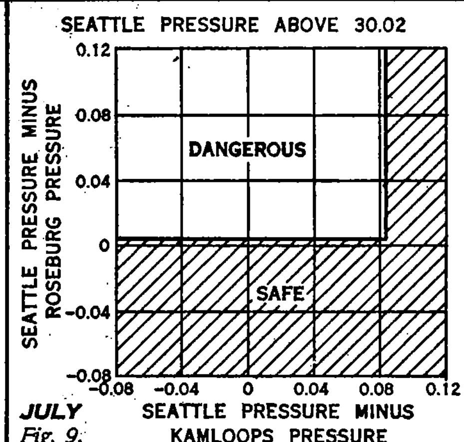

Fig. 9.

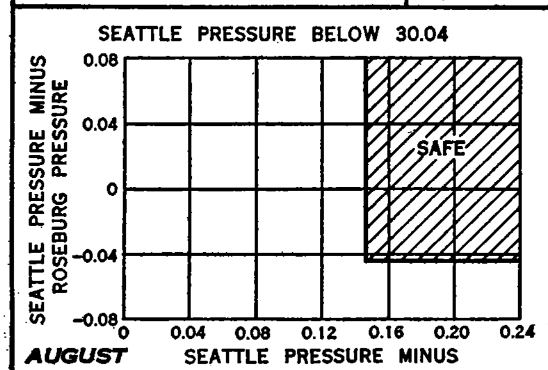

Fig. 10.

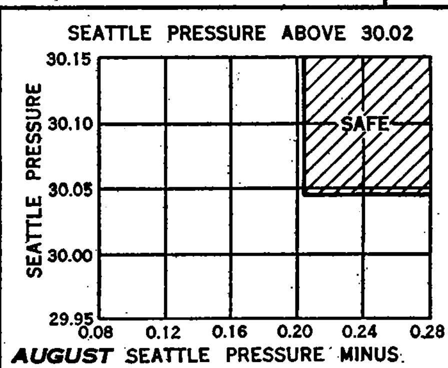

Fig. 11.

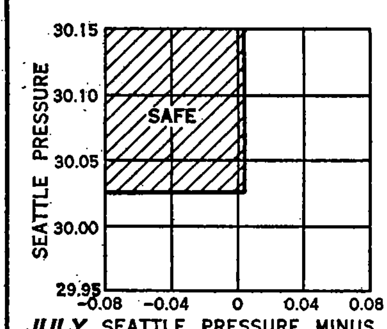

Fig. 12.

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days that occurred when the pressure was above 30.05 inches at Seattle came when the vapor pressure was above 0.34 inch at Roseburg, and the Roseburg pressure was from 0.02 to 0.10 inch lower than at Baker (fig. 5). In fact, when such a situation prevails, the probability is strongly in favor of dangerous storms over the area under consideration. During the same month, when the pressure is below 30.05 inches at Seattle, vapor pressure above 0.35 inch at Roseburg, and the pressure at Roseburg not more than 0.12 inch higher than Baker, the lightning fire hazard is great. There was a total of 53 cases during the August months when the pressure was below 30.05 inches at Seattle, but did not meet the other requirements, and only four "scattered" and no "wide-spread" storm days occurred (fig. 6).

METEOROLOGICAL CONDITIONS IN MORNING AND THUNDERSTORM ACTIVITY NEXT DAY

Studies of the same character as the foregoing were made to find relationships between meteorological elements observed at 8 a. m. E. S. T. and the occurrence of thunderstorms the following day.

The relationships described hereunder for July are intended for consideration in connection with the weather maps from June 30 to July 31, inclusive.

It was found that during July when the pressure is higher than 30.02 inches at Seattle and the pressure is higher at Roseburg than at Baker conditions are relatively safe (fig. 7). Out of a total of 98 observations no "wide-spread" and only two "scattered" storm days occurred under these conditions. There is no well defined correlation between these factors and the occurrence of thunderstorms during August.

During July conditions are relatively dangerous (thunderstorms occurring in about 50 percent of the cases) when the morning pressure at Seattle is below 30.04 inches and not more than 0.12 inch higher than at Kamloops, and in addition the pressure at Seattle is higher than at Roseburg or not more than 0.04 inch lower. On the other hand relatively safe conditions prevail when the pressure at Seattle is below 30.04 inches and the other observations do not come within the above classification. Out of a total of 41 such cases, there were 2 "wide-spread" and 1 "scattered" storm day (fig. 8).

During the same month, thunderstorms occurred in about 50 percent of the cases when the pressure at Seattle was above 30.02 inches and higher than at Roseburg, and in addition the Seattle pressure was not more than 0.08 inch higher than at Kamloops. Only 1 "wide-spread" and 3 "scattered" storm days occurred out of the 119 days when the pressure at Seattle was above 30.02 inches, and the other observations did not come within the above classification (fig. 9).

During August conditions are relatively safe when the pressure at Seattle is below 30.04 inches and more than 0.14 inch higher than at Kamloops, or if the Seattle pressure is either higher or not more than 0.04 inch lower than at Roseburg (fig. 10). Forty-five cases came within this classification and only one "wide-spread" and no "scattered" storm days occurred. With pressure higher than 30.02 inches at Seattle and more than 0.20 inch higher than at Kamloops, conditions are relatively safe (fig. 11). One "wide-spread" and one "scattered" storm day occurred under these circumstances out of a total of 35 observations.

There were no "wide-spread" or "scattered" storm days during July out of 57 cases with pressure at Seattle above 30.02 inches and the pressure at Seattle the same or lower than at Roseburg (fig. 12). Under these conditions during August, 1 "wide-spread" and 3 "scattered" storm days occurred out of 47 cases.

CONCLUSION

It is regretted that the record available for study is short and the conclusions, as mentioned above, must not be considered as final. However, it is believed that there are sufficient data to justify development of working hypotheses at the present time.

LIGHTNING STORMS AND FIRES ON THE NATIONAL FORESTS OF OREGON AND WASHINGTON

By WILLIAM G. MORRIS

[Pacific Northwest Forest Experiment Station, Portland, Oreg. Summarized by W. R. Stevens, Weather Bureau, Washington]

Lightning causes more than one-half of all the fires on the national forests of Oregon and Washington, where an average of 750 fires annually is attributed to this one cause. These lightning-caused fires cost hundreds of thousands of dollars to extinguish; they destroy an enormous amount of timber, imperil entire watersheds by destroying the cover at the headwaters of important streams and wreak heavy damage in recreational areas of these two States.

Unlike man-caused fires, which are potentially preventable, lightning fires can never be prevented. For lightning fires, the forest protectionist has recourse only to prompt detection and suppression. A single storm may start so many fires that the protective forces are strained to the utmost to reach and extinguish every fire before any attains devastating size. Since, on most national forests of the region, many of the lightning fires are at considerable distances from the areas of everyday man-caused risk, special steps must be taken to protect the lightning fire zone whenever lightning storms are expected.

The study here reported on was made (1) to discover the fundamental characteristics of lightning storms andthe fires they start so as to assist in planning the best possible systems of lightning fire control, and (2) to supply some of the basic information needed for effective lightning storm forecasting.

BASIC DATA

This study is based on more than 6,000 systematic reports describing lightning storms seen by United States Forest Service fire lookouts in Oregon and Washington during the summer months from 1925 to 1931, inclusive. During this period an average of about 200 lookouts have submitted reports each year. Each report shows the following three points concerning the location and movement of an individual lightning storm: (1) Location of the storm and the time when it was first seen by the lookout; (2) location of the storm (and in many cases the time) when it was nearest the lookout; (3) location and time when the storm was last seen by the lookout. The territory for which these reports were made includes all of the Cascade Range from southern Oregon to the British Columbia boundary, the Coast Range in western